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Achieving Environmental Performance through Design for Environment (DFE) Process in Foundry Operations

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Abstract

A detailed discussion is made on how to develop an implementation procedure for design for environment (DFE) management program. A foundry manufacturing enterprise was chosen for comprehensive assessment and recommendation in this research. The main thrust of this work was to develop theory on how DFE could be comprehensively and consistently managed in daily business situation of product development. It was realized that an integration of environmental management systems, design for Environment, and integrated product development was necessary to achieve this. It was found that an intersection existed where three areas needed to coexist. Hence, theory and a model needed to be developed that explained and guided the management of DFE in the industry. The use of DFE for foundry industry would go a long way in preserving the environment and reducing costs for production hence create more profits.

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Keywords: DFE, environmental, green, foundry, competitiveness, performance

1. Introduction

Aiming to improve environmental performance not only demonstrate responsible corporate behavior, it is critical to good business practice. Environmental protection is rapidly becoming an essential factor in business competitiveness [2]. A good environmental protection program controls claims, reduces clean up and spill mitigation cost, reduces legal fees, controls fines and penalties, and reduces insurance costs. Thus having an effective environmental protection program can also reduce operating costs by reducing the amount of resources and waste generated.

The introduction of market-based instruments of control, such as environmental producer responsibility and environmental labeling, and the growing importance of green consumerism have strengthened the incentive for design for Environment (DFE) as a business strategy at the corporate level. The reasons behind this growth are probably that DFE gives companies an opportunity not only to decrease business risks due to evolving legislation and to increase product competitiveness but also to cut costs and find new products and market segments [1, 2].

Environmental consideration in product seeks to decrease and prevent environmental problems throughout a product's life cycle as well as to gain market advantages, cost savings and minimize business risk. A number of legislations have been put in place to effect *the extended responsibility of the manufacturer* and *take-back obligation* to cover the product's entire life [3, 5].

In Zimbabwe, many organizations do not include environmental issues in their product development activities in the environmental management system. This study seeks to study how Design for Environment (DFE) can be integrated in ISO 4001. DEF would be conducted in the ISO 14001 cycle of

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plan-do-check-act (PDCA) with environmental objectives and DFE tools integrated into the traditional process of product development [5, 8].

The objective is to minimize or eliminate, during design, the anticipated waste generation and resource consumption in all subsequent life cycle phases which entail: construction, operation and closure (or production, use and disposal)

2. Background literature

2.1 Definition

Design for Environment (DFE) is the systematic consideration during design of issues associated with environmental safety and health over the entire product life cycle [3]. DFE can be thought of as the migration of traditional pollution prevention concepts upstream into the development phase of product before production and use. DFE is applied to the design of new and modification of existing products, processes and facilities.

2.2 DFE and product life cycle (PLC)

As global markets is undergoing continuous and rapid change, every company's ability to innovate and be flexible will be critical to its profitability [7,8]. DFE strategy can stimulate product innovation in areas of choice of material, production techniques, finishing technologies and packaging methods. Also partnerships with suppliers, distributors, recyclers can open up new market areas and improve product quality. While most companies do not control the whole product life cycle, their design decisions do have an impact on upstream and downstream processes, from selection of materials to product service and end-of-life options.

2.3 DFE and Environmental Management Systems (EMS)

EMS such as 14001 is an organizational approach to facilitate environmental evaluation and management. The core requirement of EMS is that a firm should have a reasonable amount of information on environmental effects of its products and processes, and seeks continuous improvement. Pollution prevention is typical part of EMS.

DFE is complementary to EMS. It enhances the organizational approach by including product-oriented environmental evaluations and improvements. Manufacturers using DFE strategies take into account the environmental aspects of a product's use and en of life, and apply this information during its design, production and distribution [3].

Motivation for DFE program arises from need to reduce Non Product Output (NPO). The cost of NPO include costs of material, warehousing, manufacturing as well as internal collection, treatment and external disposal or recycling. Hence, DFE seeks to minimize NPO or create valuable by-products from them. Typically for Aluminium die casting processing they adds up to 30 to 50% of total output by weight [3, 8].

It is important to note that high level of environmental performance can only be improved by regular reviews of related scientific information and existing environmental legislation.

2.4 DFE implementation

To implement DFE discussions are done with departmental heads and hands- on evaluation is done with plant operators as a follow-up centered on [8]:

- Hazards of the process
- Previous incidents with catastrophic potential
- Engineering and administrative controls
- Consequences off failures of engineering and administrative controls
- Facility lay out
- Evaluation of safety and health effects
- Any other regulatory issues

2.5 Benefits of DFE

DFE offers business opportunity to improve environmental performance, as well as improving profits. The companies would also reduce environmental impact of products/processes; optimize material and energy consumptions; improve waste management/pollution prevention systems; encourage good design and drive innovation; reduce costs; exceed current customer expectation for price, performance and quality; increase product marketability. DFE provides a means for establishing a long-term strategic vision of an organization's future products and operations. It is an enabling force to shape more sustainable patterns of production and consumption [3].

3. Methodology

The study was done at the case study foundry to assess the environmental aspects of product throughout its life cycle. Effort was also made to identify the environmental priorities to be delay with by the DFE process implementation. MET – matrix was used to evaluate the priority areas [6]:

- ***M****- Utilization of Materials in each stage of the Life Cycle* – this provided a view of the priority inputs by quantity, toxicity etc

- ***E****- Utilization of Energy* – this refers to transportation on each stage of the life cycle, and the impact of input energy consumption by throughout the life cycle

- ***T****- Toxic emission (all outputs: emissions, effluent or toxic waste)* – this relates to all outputs produced in the process, and gave an idea of which are the most important outputs by their toxicity.

Any other process inspections and interviews with operators were complementary to data collection to get more insights about the operations. Utility bills and purchases records provided the data required on resource consumptions for the various foundry sections.

4. Case study

Alumin Foundry Company is a non-ferrous foundry establishment which produces a wide range of aluminium alloy products that include extruded profiles, bars and gravity die castings [7]. Also included in the production range are: aluminium sections for engineering and other purposes in anodized or powder coated finishes, irrigations pipes and their fittings, as well as various castings that includes cookware. Presently, the organization employs about 112 employees in nine (9) main departments which are: Re-melting Plant, Extrusion Plant, Foundry, Anodizing and Powder Coating departments. Major flow process routes are given by Fig. 1 below.

The organization aspires to be the dominant supplier of quality products in it chosen market locally and in the region. Specific niche markets will be developed where capability and competitiveness could be demonstrated. The firm is aware of its environmental responsibilities and is in the process of implementing ISO 4001.

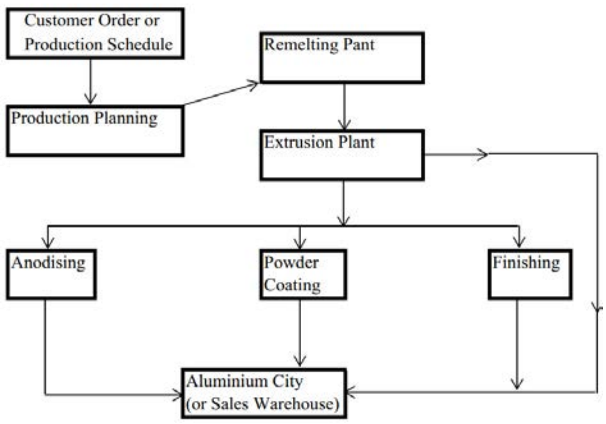

Fig. 1 Production process route

A demand or sales forecast is used to drive the production departments. Products are produced for both stock and on customer orders. Special dies are kept for customers who require specific products and also tolling production is also a part of manufacturing system. For stocking purposes, Alumin Foundry relies on an internal prioritization system that is called 'fast moving dies' system. This is whereby the company analyses its purchases from stock and identify which products are on demand over a certain period.

Re-melting plant: Aluminium scrap from various sources and aluminium high purity (HP) ingots (at a ratio of 65:35) are charged into a reverberatory furnace with a capacity of 5.5 tons. Other additions are made in smaller quantities (normally less than 20 kgs each) which include magnesium, silicon and titanium (in the form of titanium-boron rod). Aluminium and its alloys melts around 630 ºC. Once these materials have melted and the melt analysed for consistency in terms of the elemental constituents a casting process is then done. The casting that is done at Aluminium Foundry is known as direct-chill (DC) casting and from this cylindrical logs are produced. The logs produced go through a heat treatment process called homogenization and cooling after which they are then cut into smaller sections known as billets to lengths of 420, 525 and 630mm depending on the requirements of the next stage of extrusion of which the billets are the feedstock. The capacity of the furnace at is 5.5 tons and the production rate is currently at 4.8 tons per day of logs.

Extrusion plant: In the extrusion plant the billets are then forced under pressure through a die to form the various sections, bars, profiles and tubes. Before extrusion begins, the die is heated in a furnace. The die is a steel disk containing one or more cavities through which the aluminium is extruded. The die assembly is lowered into a holder and transferred into position within the press. The aluminium billets are heated to 320 – 500 ºC in order to make them soft. The billets are often heated so that the front end is hotter than the rear (taper heating). This is because as the billet progressively deforms in the press, it also heats up due to friction and deformation. The main extrusion cycle begins and as the profile emerges, it is cooled using air or water sprays in order to develop its metallurgical properties. This process is known as direct extrusion and the products so produced have what is known as a mill surface finish. At the end of extrusion, there is still a small length of billet remaining. This 'butt end' is sheared off in order to present a flat face for the subsequent billet to join onto. The extrusion is sawn off just past the cooling zone and then transferred to the stretcher.

Anodizing plant: Anodising is an electrochemical reaction which is used to protect and give a coloured finished to an aluminium section. The reaction is based on the fact that pure aluminium when exposed to the atmosphere it reacts to give a thin oxide layer on the aluminium which is very resistant to most chemical attacks. The anodizing process is used to enhance the formation of this oxide layer and also to give the aluminium some colour. At Aluminium Foundry the anodizing process is done as a batch operation where sections are first assembled on a jig. This jig takes the form of a rectangular shape formed by bars onto which the aluminium sections are tied using aluminium wire. The cycle time for the process from jigging to the last stage known as sealing is about 150minutes. The target per day for the department is 400 m2 of anodized sections.

Powder coating plant: Powder coating is a process used to put a coloured finish to an aluminium section. Powder coating is an electrostatic deposition process where a powder is energized and sprayed onto a pre-treated aluminium section. Various colours depending on the customer specification can be done at Alumin Foundry. About 60 colours can be done. The cycle time for this process is about 90 minutes.

Dispatch process: Once processing of the material is complete, the ticket is completed and sent to the production controller for the department. The production planner then issues transfer notes for the material to be moved to the relevant next section or to the customer. It is envisaged that the whole process from customer order to the dispatching of the material to the customer takes between 3 to 6 weeks. The dispatch rule at Alumin Foundry is basically the 'first in first out rule' (FIFO).

5. Results and Discussion

5.1 Energy

At Almin Foundry there was a lot of high powered machinery which has high demand for power in the plant, meaning there existed poor load factor i.e maximum demand was higher than energy demand.

5.2 Production section and environmental impact

5.2.1 Aluminium re-melting section

Fig.2 gives the inputs and outputs flow of the Aluminium re-melting section to produce logs which are anodized in the next. Also waste generated in form of scrap and emissions was noted. Table 1 below summarizes the adverse environmental impact of emissions produced by the processes in this section.

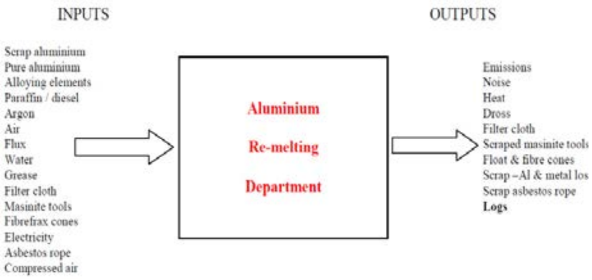

Fig. 2 Aluminium re-melting process material flow

Table 1. Environmental impact of re-melting section

Affected element of the environment or Aspect	Impact / effect	Significance Rating (1 to 3), I
Air (atmosphere) by fuel burning	Air pollution SO_x, NO_x, CO, CO_2, contribute to global warming	3
Surface water	Acid rains contaminates the surface water	3
Natural resources	Potential depletion of resources	3
Flora	Destroyed by acid rains	3
Humans	Nitrogen oxide + V.O.C in the presence of sunlight produce the lower atmospheric ozone which cause inflation of the lungs	3
Fauna	Affected by acid rains	3
Land	Potential spillage cause pollution	3
Disposal of dross	Land pollution by AlO_3, Al, flux elements	3
Use of machinery	Noise, potential accidents	2
Diesel/Parafin/LPG storage	Danger of fire	2

Impact effect (level of danger) shown in the table, is rated as follows:

- o If the risk is fatal or leads to penalty I=3
- o If the risk is presented in the long term the I = 1
- o If the risk is presented in short term then I=2

5.2.2 Aluminium extrusion section

Fig.3 gives the inputs and outputs flow of the Aluminium extrusion section to produce Alumium sections which are the input for the extrusion process. Also waste generated in form of swarf, effluent, fumes and cut off scrap was noted. Table 2 below summarizes the adverse environmental impact of the mentioned waste produced by the processes in this section.

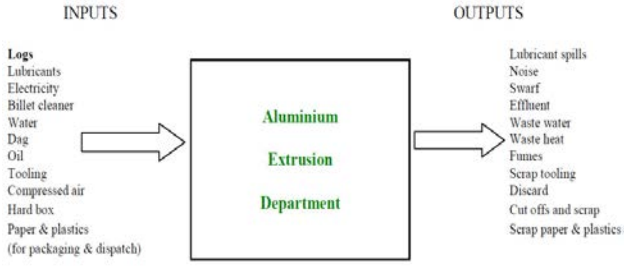

Fig. 3 Aluminium extrusion process material flow

Table 2. Environmental impact extrusion section

Affected element of the environment	Impact / effect	Significance Rating (1 to 3), I
Surface water	Potential spillage lubricant contaminating the storm water drains & sewer	3
Underground water	Potential contamination if effluent seepage occurs	3
Land	Contamination if lubricant spillage occurs	3
Natural resources	Depletion of natural resources	2
Flora	Destroys vegetation	2
Fauna	Kills insects and ants	3

5.2.3 Aluminium anodizing section

Fig.4 gives the inputs and outputs flow of the Aluminium anodizing section to produce work in progress sections which are the input for the powder coating process. Also waste generated in form of fumes, water effluent and acid spillage effluent was noted. Table 3 below summarizes the adverse environmental impact of the mentioned waste produced by the processes in this section.

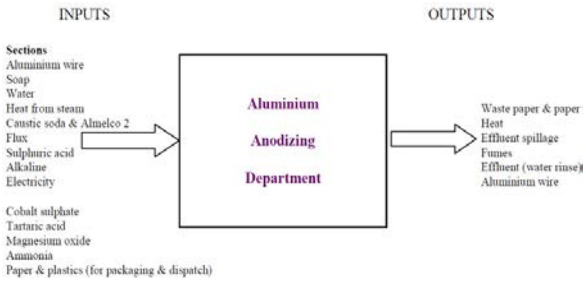

Fig. 4 Anodizing process material flow

Table 3. Environmental impact extrusion section

Affected element of the environment/ Apect	Impact / effect	Significance Rating (1 to 3), I
Surface water	Pollution of surface water if spillages occur & released untreated	3
Underground water	Pollution of underground water if leakages occur	3
Land	Pollution if leakages occur	3
Humans	Very toxic to humans if not handled properly	2
Flora	Destroys plants if effluent finds its way to & waters	3
Emissions from tanks	Injuries to workers when contact with skin, inhaled or ingested	3
Disposal of anodizing sludge	Potential sewer pollution if untreated effluent discharged	3
Use of electricity	High energy intensity	2
Use of machinery	Noise pollution	1
Fauna	Can be intoxicated if consumes food contaminated by effluent	3

5.2.4 Aluminium powder coating section

Fig.5 gives the inputs and outputs flow of the Aluminium powder coating section to produce final surface finish for the sections before dispatch. Also waste generated in form of fumes, powder dust, metal scrap, water effluent and spillage effluent was noted. Table 4 below summarizes the adverse environmental impact of the mentioned waste produced by the processes in this section.

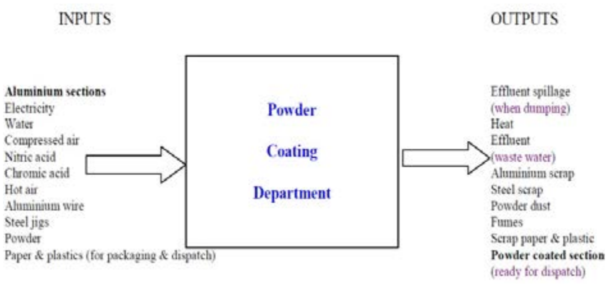

Fig. 5 Powder coating process material flow

Table 4. Environmental impact extrusion section

Affected element of the environment/ Apect	Impact / effect	Significance Rating (1 to 3), I
Surface water	Pollution of surface water if spillages occur & released untreated	3
Underground water	If seepage occurs	3
Land	Land contamination if spillages occur	3
Emission of powder dust	Air pollution	2
Humans	Can have harmful effects if contact with skin, inhaled etc.	2
Flora	Destroys plants if effluent finds its way to & waters	3
Emissions from tanks	Injuries to workers when contact with skin, inhaled or ingested	3
Disposal of powder coating effluent & sludge	Sewer, land & water pollution	3
Use of chemicals	Sewer, land & water pollution	3
Use of machinery	Noise pollution	1
Fauna	Effluent has high heavy metal concentration and toxic to fauna if consumed	3

It was noted that use of chemicals resulted in generation of fumes, effluent spillages and waste water effluent to the detriment of the environment. This also posed a high risk to operators and in some instances potential for explosions if fuels and acids are not handled well. Other DFE measure had just been taken for instance the replacement of Chlorine gas with Argon in the degassing process.

6. Recommendations

High power demand could be reduced through load shedding and staggering the times of switching on equipment in the plant. As well as sub-metering various sections of the plant with view to closely monitoring major consumer sections as well as maintaining a good load factor for key equipment.

In the re-melting section, all scrap is recycled but it is the handling of dross that requires improvement by building a concrete wall with side walls so that errant dross spillage do not affect biodiversity as it has to be disposed of in an environmentally friendly manner . Dross contains soluble halides, heavy metal residues and toxic components. A mini dross recycling plant can also be put in place.

A proper charger for the furnace is required instead of using the forklift or hands to charge the furnace. Instead of using gravity die casting, pressure die casting should be taken on board to produce products of varying thickness with accuracy. All the used oil can be drained and mixed with paraffin and used to fire the furnace.

In the extrusion area, the nitriding plant should be rectified as there are signs of ammonia emissions.

Sludge from anodizing plant could be regenerated into Aluminium sulphate, which can be used for cleaning water and as cement filler.

All packaging waste such as plastics and card board boxes have to be segregated and sent to vendors for recycling.

Water and energy sub-metering to pursue to reduce consumption levels by section and by process.

Other critical area to be investigated is for management to quantify the cost of non-product out (NPO), and try to reduce this hidden cost which exist in the normal way of doing business at the plant.

7. Conclusion

The analysis of the case study has shown that in Zimbabwe, most organizations are not aware of DFE and have not taken EMS as a competitive advantage. Some of the DFE techniques adopted so far at the case study organization as part of their best practice initiative, have yielded significant benefits. The areas identified for DFE implementation are designing for resource conservation, low-impact material, biodiversity conservation, cleaner production, reuse, recycling and safe disposal in the aluminium foundry.

The environmental benefits of keeping aluminium waste out of landfills are proving of interest to foundries and environmentalists. While companies reclaim aluminium from dross, none is known to recycle the remaining elements to achieve practically no waste. Aluminium and its alloys can be melted and recast time and again, producing metal with the same properties as primary aluminium. This is why recycled aluminium retains high scrap value, which drives for further recycling.

The issue now would be to implement companywide DFE and constantly evaluating and reviewing progress through guidelines of ISO 4001for full benefits to accrue to the organization.

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